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TITLE OF THE INVENTION

Optical Proximity Spatial Transmission System

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a data communication made optically between transceivers located in proximity of, but not in contact with, each other.

This application claims the priority of the Japanese Patent Application No. 2002-220057 filed on July 29, 2002, the entirety of which is incorporated by reference herein.

Description of the Related Art

The conventional popular communications systems may be classified roughly according to their basic categories into a proximity communication and telecommunication as shown in FIGS. 1 and 2, respectively. As will be known from FIGS. 1 and 2, the proximity communication and telecommunication may further be classified according to their physical features into a contact type and noncontact type. Each of these contact and noncontact type communications is advantageous for some applications but not for other applications. That is, selection of any one of such communication types depends upon an intended use and peripheral conditions.

For example, in case the following requirements have to be met:

(1-1) A proximity communication should be made between two communication devices, or between one and many such devices;

(1-2) The devices should not be in contact with each other during communications:

(1-3) Each of the devices not in contact with the other(s) should be able to keep its quality performance of communications even while it is being moved, rotated or oscillated (within a certain range) during communications;

(1-4) The baud rate is 200 Mbps or more;

(1-5) During communication, each of the devices should not adversely affect any nearby electronic circuit, electronic device or the like;

(1-6) It should be as unlikely as possible that data being transmitted is intercepted; and

(1-7) The manufacturing cost should be as low as possible,

that is, in case the aspects of the communication, indicated as enclosed in a block 501 in FIG. 1, have to be attained, the communication apparatus has to be a proximity communication one and it should be of a noncontact type, as in the above items (1-1) and (1-2). To transmit a digital signal at a rate of 200 Mpbs, the communication device has to use an electromagnetic wave (radio) data communication or a proximity optical data transmission.

As having been already known, the electromagnetic wave (radio) communications meet the high-speed communication requirements and have not many problems even if the physical relationship between communication devices varies.

Disadvantageously, however, since the communication devices use an electromagnetic wave for communications between them and the baud rate is 200 Mbps or more, the communication wave will inevitably affect more or less any nearby electronic circuit, electronic device or the like and the latter vice versa. To avoid the above, the transmission/reception circuit has to be designed with large costs, or an electromagnetic shielding has to be provided. Also, in this electromagnetic communications system, since an electromagnetic wave with a power is emitted in a space because communications are done electromagnetically, signal data carried by the radio wave is intercepted unavoidably, which is the most important problem. To avoid the interception as far as possible, couplings have to be shielded perfectly with e.g., an electromagnetic shielding material. For each of the communication devices to be movable, rotatable or oscillatable as in the above item (1-3), it is rather difficult because of the requirement as in the item (1-7) to perfectly shield the moving parts such as the couplings.

On the other hand, the optical proximity spatial communication is not any radio communication. So, it is incomparably superior in anti-interception to the radio communication. Signal data transmitted by this system can little be intercepted by the third party. The security of this communication system is rather high. Also, signal data carried by light will not basically interfere with any radio waves. Use of a communication-oriented semiconductor laser diode permits to make communications at a speed of about several GHz to about several ten GHz. This high speed can be

attained by sending signal data through direct modulation of laser light. However, emitted laser light having a spot diameter will be little spread because of its property, and travel straight because it is a kind of light. Therefore, the physical relationship between mating optical communication devices has to be controlled with a rather stricter accuracy than in the radio communication system.

Because of the structure of the semiconductor laser diode, emitted laser light will generally spread at a constant angle of emission, not similarly to other gas lasers. However, the reach of the emitted laser light is limited incomparably with the electromagnetic (radio) wave. Therefore, the physical relationship between the communication devices is limited largely, which is a critical problem in adoption of the optical proximity spatial communication.

Even if the above problems are solved, practical optical communication devices have a variety of problems. The problems will be described concerning some examples having so far been proposed. In the examples, a short-range communication is implemented by some method and applied in various devices.

Conventionally, in some of various control robots each installed on a rotating block or having a rotating part mounted thereon, measuring instruments installed on a rotating block, game machine controllers which are manually handled by a user to input a kind of command to the machine by rotating them, and the like, a variety of control data is transmitted from a stationary side to a part rotating around the axis thereof or vice versa, or a power is supplied from a stationary side to a rotating part.

FIG. 3 shows a general approach for the above purposes, in which there are used a brush 11 and a slip ring 21 which is rotatable around the axis thereof while bearing a measure of pressure applied to the brush 11. The brush 11 is provided at a stationary side 10 and fixed to a brush fixture 12 provided on a stationary base 13. Wires 14 are connected to the bottom of the stationary base 13. On the other hand, the slip ring 21 is provided at a rotating side 20 rotatably around the axis thereof on a base 23. The slip ring 21 has formed thereon contacts 22 with which the brush 11 will be put into contact when the brush 11 on the stationary side 10 is forced to the slip ring 21 under a measure of pressure. Also, wires 24 are connected to the bottom of the base 23.

In the approach using the brush 11 and slip ring 21, however, electrically conductive metal pieces, namely, the brush 11 and slip ring 21, should be rotated while being kept in contact with each other. So, the approach is not advantageous as will be described below:

(2-1) The brush 11 and slip ring 21 are short in life because of their abrasion, and signal data transmitted between them are degraded due to the abrasion and adhesion of metal powder resulted from the abrasion and dust; and

(2-2) The life of the brush 11 and slip ring 21 is further shortened in case the rotating block rotates at a very high speed, and the signal data cannot completely be transmitted since the brush 11 jumps even with a small

off-axis deviation and slight deformation of the slip ring 21.

To overcome the drawbacks of the approach using the slip ring and brush, a transmitter designed to a rotating body, which adopts the theory of electromagnetic coupling, has been proposed in the Japanese Unexamined Patent Application Publication No. H07-065281, for example. The invention disclosed in the Japanese Unexamined Patent Application Publication No. H07-065281 is a method of fixing the rotating-body transmitter. The rotating-body transmitter is destined for use in a rotating-body telemetering system which transmits measured data such as a strain, vibration, torque, temperature, acceleration, etc. of a rotating body to a stationary side and indicates the measured data. The rotating-body transmitter adopts the theory of electromagnetic coupling for data transfer from the rotating side to stationary side, and for supply of a power from the stationary side to rotating side.

The basic structure of the electromagnetic coupler based on the aforementioned theory of electromagnetic coupling is shown in FIGS. 4A and 4B. The electromagnetic coupler shown in FIGS. 4A and 4B is a rotating electromagnetic coupler, for example. FIG. 4A is a plan view of the coupler, and FIG. 4B is a sectional view of the coupler taken along the line X-X' in FIG. 4A. The rotating electromagnetic coupler, indicated with a reference 30, consists of a stationary body 31 and a rotating body 32, opposite to each other with a small gap 33 defined between them. The rotating body 32 includes a core 34a having formed therein concentrically circular grooves in each of which a coil 35a is wound. The stationary body 31 includes a core 34b having formed therein

a concentrically circular groove in each of which a coil 35b is wound. When the rotating body 32 rotates around the axis thereof, it is electromagnetically coupled to the stationary body 31 by the coils 35a and 35b and thus data can be transferred between the rotating and stationary bodies 32 and 31.

Normally, having no direct physical contact as in the approach using the slip ring, the electromagnetic coupling permits a better data transfer than that using the slip ring. However, data transfer or power supply using the electromagnetic coupling is not advantageous as follows:

(3-1) The coils 35a and 35b of the stationary and rotating bodies 31 and 32, respectively, face each other with the small gap 33 defined between them. The gap 33 normally has to be controlled strictly in the process of production on the order of μm, because of the reason that if the gap 33 between the stationary and rotating bodies 31 and 32 is not formed precisely during the production or changes due to the rotation of the rotating body 32 in operation, the efficiency of signal transmission will seriously be affected and the amplitude of received signal will vary more largely. To control the gap 33 on the order of several μm to prevent such a phenomenon, however, requires a large man-hour and advanced techniques. Therefore, this approach cannot be said to be economic.

(3-2) It is well known that since this approach is based on the theory of electromagnetic coupling, only a limited range of high frequency can be

used for transfer of a high-frequency signal when the efficiency of transmission is taken in account. Currently, the high frequency used in this field is limited to about 100 MHz. Thus, the transfer rate is limited correspondingly.

(3-3) For transmission of a signal of higher frequency than the limit in the item (3-2), the coils may be made each as a multichannel one for parallel transmission of the signal as one of possible measures. However, the occupancy of the transmission block will be larger for the increased number of channels and the cross-talk between the channels have a larger influence. So, it is difficult to make a high quality signal transmission. More specifically, in case there is additionally provided a power supply unit which supplies a power from the stationary block to the rotating block on the basis of the electromagnetic-coupling theory, the amount of AC power supplied to the coils will naturally be larger when the power consumption of the rotating block is very large, and the source current will flow to a data transmitter which is similarly based on the theory of electromagnetic coupling, which will possibly cause the transmitted data to be degraded very much.

Also, the Japanese Unexamined Patent Application Publication No. 2001-044940 discloses a technique related to an optical transmission by a rotating optical coupler. This approach is as follows. That is, a set of optical transceivers is provided

at each of stationary and rotating sides, a receiver block of the optical transceiver is disposed near the center axis of rotation and a transmitter block is also disposed near the center axis of rotation at an angle in relation to the receiver block at the other side, stationary or rotating. Also, the transceivers are disposed for the transmitter blocks at the stationary and rotating sides, respectively, not to touch each other and for light emitted from one of the transmitter blocks to interfere with light emitted from the other transmitter block as less as possible. To this end, the optical transmission system has to include a case "that can determine optical axes of a light emitter and photodetector, respectively, limit emission of unnecessary light beams from the light emitter, and limit incidence of unnecessary light upon the photodetector". This case will add to the manufacturing costs of the optical transmission system, and this approach is not advantageous as follows:

(4-1) For light emitters (transmitter) not to touch each other, the gap between the rotating and stationary sides has to be increased correspondingly, which will make it difficult to design any more compact optical transmission system.

(4-2) In case the optical transmission system includes the above "case that can determine optical axes of a light emitter and photodetector, respectively, limit emission of unnecessary light beams from the light emitter, and limit incidence of unnecessary light upon the photodetector", since the light emitters are disposed at a certain angle, the transceivers themselves

should be installed with a rather high precision and also the gap between the stationary and rotating sides should be determined with a high accuracy. If the gap height is not accurate, the spot of transmitted light, on the incident surface of the photodetector, will incur an off-axis deviation in a direction parallel to the rotation (in a direction perpendicular to the axis), so that the amount of light incident upon the incident surface will possibly vary largely.

(4-3) Also, if the "case that can determine optical axes of a light emitter and photodetector, respectively, limit emission of unnecessary light beams from the light emitter, and limit incidence of unnecessary light upon the photodetector" is disposed as near to the axis as possible, the angle of the light transmitter is increased up to about 90 degree. At this time, the incident light from one of the light emitters (light transmitter) is likely to be scattered by small irregularities of the incident surface of the photodetector and those existent near it and incident upon the other photodetector.

OBJECT AND SUMMARY OF THE INVENTION

It is therefore an object of the present invention to overcome the above-mentioned drawbacks of the related art by providing an improved and novel optical proximity spatial transmission system capable of high quality optical transmission between transceivers thereof located in proximity of, but not in contact with, each

other.

The above object can be attained by providing an optical proximity spatial transmission system for transmitting information data optically through a local space, the system including according to the present invention:

a first communication device having a light emitter and/or photodetector installed thereon;

a second communication device having installed thereon a photodetector which detects light from the light emitter of the first communication device and/or a light emitter which emits light toward the photodetector of the first communication device; and

an anti-scattering lens disposed behind the light emitter and/or in front of the photodetector of the first communication device and/or second communication device;

the first communication device being rotatable around the axis thereof aligned with the optical axis of light outgoing from the light emitter and/or light incident upon the photodetector while the second communication device with the photodetector and/or light emitter is fixed on the optical axis.

These objects and other objects, features and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 explains the proximity communication.

FIG. 2 explains the telecommunication.

FIG. 3 shows the slip ring and brush for supply of a power.

FIG. 4A is a plan view, and FIG. 4B is a sectional view, of the rotating electromagnetic coupler.

FIG. 5 shows a first basic construction of an optical proximity spatial transmitter.

FIG. 6 shows a second basic construction of the optical proximity spatial transmitter.

FIG. 7 shows a third basic construction of the optical proximity spatial transmitter.

FIG. 8 shows an off-axis deviation.

FIG. 9 shows a fourth basic construction of the optical proximity spatial transmitter.

FIG. 10 is a circuit diagram of the optical proximity spatial transmitter of the above third basic construction.

FIGS. 11A and 11B explain a semiconductor laser used in the light emitter.

FIG. 12 lists examples of optical system designs.

FIG. 13 also lists examples of optical system designs.

FIG. 14 shows an off-axis deviation.

FIGS. 15A and 15B show examples of measured optical-axial distance of spatial transmission between an LD (laser diode) and PD (photo diode) and amplitude of received signal.

FIG. 16 is a sectional view of a rotating optical coupler with a power transmission by electromagnetic coupling.

FIG. 17 is a circuit diagram of the rotating optical coupler with the power transmission by electromagnetic coupling.

FIG. 18 shows eye patterns of serial data at the receiving side.

FIG. 19 is a sectional view of a rotating optical coupler with a power transmission by a slip ring/brush combination.

FIG. 20 is another circuit diagram of the rotating optical coupler with the power transmission by electromagnetic coupling.

FIG. 21 shows the construction of a system composed of a personal digital assistant (PDA) with a high-speed communication function, and a cradle for the PDA.

FIG. 22 schematically shows the construction of a rotating monitoring VTR camera system.

FIG. 23 is a block circuit diagram of the rotating monitoring VTR camera system.

FIG. 24 is another block circuit diagram of the rotating monitoring VTR camera system.

FIG. 25 shows the external view of a rotating drum head unit.

FIG. 26 is a block circuit diagram of the rotating drum head unit.

FIGS. 27A and 27B show an optical system of the rotating drum head unit.

FIGS. 28A to 28D show another optical system applicable to the rotating drum head unit.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following, there will be explained some embodiments of the present invention with reference to the accompanying drawings. First, the present invention can basically be constructed as will be described below:

The first basic construction of the present invention is an optical proximity spatial transmitter indicated with a reference 40 in FIG. 5. As shown, the optical proximity spatial transmitter 40 consists of a first communication device (A) 42 having installed thereon a laser diode (LD) 41 provided with a lens and which emits laser light, and a second communication device (B) 44 having installed thereon a photo diode (PD) 43 provided with a lens and which detects the laser light from the first communication device (A) 42. In this transmitter 40, the LD 41 and PD 43 are placed opposite to each other and spaced from each other by a small gap 45 of several μm to several cm to provide an optical path between the first and second communication devices (A) 42 and (B) 44. Information data is transmitted along the optical path from the first communication device (A) 42 to the second communication device (B) 44 at a high transfer rate of 200 Mbps or more.

An anti-scattering lens is provided either behind the LD 41(namely, to the PD

43 side of the LD 41) or in front of the PD 43(namely, to the LD 41 side of PD 43), or both behind the LD 41 and in front of the PD 43 to prevent light scattering of laser light emitted by the LD 41 or laser light incident on the PD 43. The spot diameter, at the LD 41, of light from the LD 41 toward the PD 43 is set larger than the diameter of a light spot at the PD 43 and larger than the oscillation in a direction of off-axis deviation.

The optical proximity spatial transmitter 40 is used for local communication between the communication devices (A) and (B) in a one-to-one relation. These communication devices (A) and (B) will not be put into contact with each other during a communication, and will keep a quality performance of communication while being moved, rotated or oscillated within a predetermined range during the communication.

Also, the optical proximity spatial transmitter 40 can make data transfer at a high rate of 200 Mbps or more with a minimum influence on any nearby electronic circuit, electronic device etc. and a minimum possibility of interception of data being transmitted, and it can be produced with a reduced cost. That is, the optical proximity spatial transmitter 40 meets the requirements having previously been described.

Next, the second basic construction of the optical proximity spatial transmitter according to the present invention will be described with reference to FIG. 6. This transmitter is indicated with a reference 40' in FIG. 6. As shown, it consists of a first communication device (A') 42 having the PD 43 installed thereon and a second communication device (B') 44 having the LD 41 installed thereon. The LD 41 and PD

43 are disposed opposite to each other and spaced from each other by the gap 45 of several μm to several cm.

Of course, the optical proximity spatial transmitter 40' has also one optical path along which information data is transmitted from the second communication device (B') 44 to the first communication device (A') 42 at a high transfer rate of 200 Mbps or more.

Also in this transmitter 40', an anti-scattering lens is provided either behind the LD 41 (namely, to the PD 43 side of the LD 41) or in front of the PD 43(namely, to the LD 41 side of PD 43), or both behind the LD 41 and in front of the PD 43. Further, the spot diameter, at the LD 41, of light from the LD 41 toward the PD 43 is set larger than the diameter of a light spot at the PD 43 and larger than the oscillation in a direction of off-axis deviation.

Then, the third basic construction of the optical proximity spatial transmitter according to the present invention will be described with reference to FIG. 7. This transmitter is indicated with a reference 50 in FIG. 7. As shown, it consists of a first communication device (A) 52 having installed thereon an LD 51 provided with a lens and which emits laser light and which is rotatable around an axis of rotation 56, and a second communication device (B) 54 having installed thereon a PD 53 provided with a lens and which detects the laser light from the first communication device (A) 52 and which is stationary. In this transmitter 50, the LD 51 and PD 53 are placed opposite to each other and spaced from each other by a small gap 55 of several μm to several

cm to provide an optical path between the first and second communication devices (A) 52 and (B) 54. Information data is transmitted along the optical path from the first communication device (A) 52 to the second communication device (B) 54 at a high transfer rate of 200 Mbps or more.

Since the first communication device (A) 52 is rotatable around the axis of rotation 56, the amplitude of received signal varies in Z, Y and X directions due to a rotation-caused oscillation while the signal is traveling along the A-to-B optical path as shown in FIG. 8. An off-axis deviation takes place in the Z direction. The X direction is a direction of the spatial distance (optical-axial direction). The Y direction is a direction perpendicular to the X and Z directions. In this transmitter 50, an anti-scattering lens is provided either behind the LD 51(namely, to the PD 53 side of LD 51) or in front of the PD 53(namely, to the LD 51 side of PD 53), or both behind the LD 51 and in front of the PD 53 to limit the variation of the amplitude of received signal in the range allowed at the receiving side. Further, the spot diameter, at the LD 51, of light from the LD 51 toward the PD 53 is set larger than the diameter of a light spot at the PD 53 and larger than the oscillation in a direction of off-axis deviation.

The optical proximity spatial transmitter 50 is used for local communication between the communication devices (A) and (B) in a one-to-one relation. These communication devices (A) and (B) will not be put into contact with each other during a communication, and will keep a quality performance of communication while being moved, rotated or oscillated within a predetermined range during the communication.

Also, the optical proximity spatial transmitter 50 can make data transfer at a high rate of 200 Mbps or more with a minimum influence on any nearby electronic circuit, electronic device etc. and a minimum possibility of interception of data being transmitted, and it can be produced with a reduced cost. That is, the optical proximity spatial transmitter 50 meets the requirements having previously been described.

Next, the fourth basic construction of the optical proximity spatial transmitter according to the present invention will be described with reference to FIG. 9. This transmitter is indicated with a reference 50' in FIG. 9. As shown, it consists of a first communication device (A') 52 having the PD 53 installed thereon and which is rotatable, and a second communication device (B') 54 having the LD 51 installed thereon and which is stationary. The LD 51 and PD 53 are disposed opposite to each other and spaced from each other by the gap 55 of several μm to several cm.

Of course, the optical proximity spatial transmitter 50' has also one optical path along which information data is transmitted from the second communication device (B') 54 to the first communication device (A') 52 at a high transfer rate of 200 Mbps or more.

Also in this transmitter 50', an anti-scattering lens is provided either behind the LD 51(namely, to the PD 53 side of LD 51) or in front of the PD 53(namely, to the LD 51 side of PD 53), or both behind the LD 51 and in front of the PD 53. Further, the spot diameter, at the LD 51, of light from the LD 51 toward the PD 53 is set larger than the diameter of a light spot at the PD 53 and larger than the oscillation in a

direction of off-axis deviation.

Next, the circuit of the optical proximity spatial transmitter 50 of the third basic construction is constructed as will be described with reference to FIG. 10. As shown, a data signal complying with an electrical signal standard, sent from a sending-side device 57, is supplied to an interface circuit 521 of the first communication device 52. The interface circuit 521 converts the data signal complying with the electrical signal standard adopted in the sending-side device 57 into a signal complying with a standard suitable for an LD driver 522. Currently, for dealing with a signal of 200 Mbps or more, a differential-transmission emitter-coupled logic (ECL) is commonly used as a signal standard. However, in case a signal from the sending-side device 57 is not at the ECL level, it should be converted according to the signal standard to a level suitable for the LD driver 522. For example, TTL (transistor-transistor logic) level is converted to PECL (positive emitter-coupled logic) level.

The data signal processed by the interface circuit 521 to have a suitable level is sent to the LD driver 522. Applied with an appropriate forward bias which depends upon the LD 51 to drive the latter, the LD driver 522 produces an LD drive current corresponding to the data signal. The LD drive current is supplied to the LD 51. The LD 51 emits a light modulation signal corresponding to the data signal, and sends the light modulation signal in the form of laser light.

The PD 53 of the second communication device 54 detects the light modulation signal, makes photoelectric conversion of the signal to produce a weak current signal

and sends the current signal to a trans-impedance amplifier 541. The trans-impedance amplifier 541 amplifies the weak current signal while limiting the frequency band of the signal, and supplies the amplified signal to an interface circuit 542.

The interface circuit 542 corrects the variation in amplitude of the received signal, due to a variation in distance between the first and second communication devices 52 and 54, determines a threshold level to judge the logic level of the signal while converting the supplied signal into a one whose level complies with the signal standard adopted at a receiving-side device 58 connected to the interface circuit 542. The converted signal is sent to the receiving-side device 58.

In the optical proximity spatial transmitter 50, the first and second communication devices 52 and 54 are designed to be movable, rotatable and oscillatable. Therefore, the optical path is oscillatable in the following directions:

(5-1) Off-axis direction

(5-2) Direction of distance between the light emitter and photodetector (spatial-distance direction)

(5-3) Direction perpendicular to off-axis direction

The magnitude of each of the above oscillations varies depending upon the operating conditions of an apparatus with which the transmitter according to the present invention is used, required specifications and set costs of the apparatus.

Therefore, the optical system of the optical proximity spatial transmitter should be designed to attenuate the oscillations in the above items (5-1) to (5-3) for

maintenance of the state of a received signal within a range allowed by the apparatus with which the transmitter according to the present invention is used.

Here will be described some examples of the optical system, examples of oscillations and accuracy of rotation allowable in such optical systems, and addition of an AGC circuit. According to the present invention, the optical system is designed as will be described below:

First, the LD (laser diode) 51 installed in the first communication device 52 of the aforementioned optical proximity spatial transmitter 50 will be described.

FIGS. 11A and 11B show together the structures of conventional semiconductor laser diodes and far-field patterns (FFP). More specifically, FIG. 11A shows an edge emitting laser diode, and FIG. 11B shows a surface emitting type laser diode commonly called "VCSEL (vertical cavity surface emitting layer)". The edge emitting type laser diode widely used provides an elliptic FFP as shown in FIG. 11A. The surface emitting type laser diode shown in FIG. 11B is inexpensive and provides a circular FFP as shown. The latter example of laser diode is suitable for use in the embodiment of optical proximity spatial transmitter according to the present invention in which the LD in one of the communication devices sends optical data toward the PD of the other communication device. Of course, any other LD than VCSEL will do, too.

Next, design examples of the optical system of the transceiver block will be explained. The examples are intended for preventing light scattering to improve the efficiency of light transmission/reception.

For an improved efficiency of light transmission/reception, light emitted from the light emitter (laser diode: LD) 51 is converged through a collimator lens or the like, which will be explained herebelow. For adoption of a more suitable manner of light collimation, consideration should be given to the rotation accuracy of a rotating system employed and manufacturing cost.

FIG. 12 shows optical-system design examples of types A to C, and FIG. 13 shows optical-system design examples of types D to F, each along with evaluation results of a communication efficiency, spatial transmission distance, X-axial photodetection width, Y- and Z-axial photodetection width, aptitude and economical efficiency. The X, Y and Z axes are shown in FIG. 14.

In the optical system of type A, the LD and PD are simply disposed directly opposite to each other without any lens laid between them. In this design of type A, light from the LD is diverged at an angle θ, and the PD has no measure for collecting the diverged light. So, the spatial transmission distance is rather short and communication efficiency is low. Therefore, the optical system of type A may be possible if the LD-PD distance is short but it is not practically usable.

The optical systems of types B to F are different from each other in insertion and combination of a condenser lens used especially to prevent light scattering. Each of these optical system designs will be discussed concerning its features.

The type B uses an LD package with a lens. No lens is provided at a PD package. Light emitted from the LD at a predetermined angle θ is collimated by the

lens accessory to the LD package for incidence upon the PD. Therefore, the received signal amplitude varies less even with a change of the optical-axial spatial transmission distance. Also, when the off-axis deviation falls within the range of a spot diameter which depends upon the distance from the LD to the lens, the amplitude of received signal will little vary. Further, the transmission efficiency is slightly low since no image is formed on the incident surface of the PD, but it is possible to suppress noise occurrence and unstable light emission caused by return laser light and which are problems in designing of a focusing optical system. However, the suppression of noise occurrence and unstable light emission depends upon a laser used.

In the optical system of type C, no lens is provided at the LD package but a lens is provided at the PD package to condense light onto the incidence surface of the PD. In this type C, light from the laser emitting surface of the LD is spread at a predetermined angle θ and thus the spot diameter is increased. At the PD package, the spread light is partially collected by the lens for incidence upon the PD. In this optical system, the spot diameter can be increased by increasing the spatial transmission distance between the stationary and rotating sides. Therefore, this optical system will do even with a low rotation accuracy of the rotating body in the direction of off-axis deviation. On the contrary, if the rotation accuracy in the optical-axial direction is low, namely, if the optical-axial spatial transmission distance varies, the amplitude of received signal will slightly vary. Also, since the incident light is basically formed as an image on the incidence surface of the PD, the transmission efficiency appears good.

However, since the spatial transmission distance is increased and the PD detects only a part of the light from the LD, the actual efficiency is not so high.

In the type D, light emitted from the LD at a predetermined angle θ is collimated by a lens accessory to the LD package, and further collimated by a lens provided at the PD package for incidence upon the incident surface of the PD. The optical system of this type D is higher in transmission efficiency than the aforementioned types A to C, and it can advantageously be used in an optical proximity spatial transmitter in which the spatial transmission distance has to be increased. Also, in this type D, the amplitude of received signal varies less even with a change of the optical-axial spatial transmission distance while the amplitude of received signal varies to a certain extent due to a variation in optical off-axis direction. However, the lens provided at each of the LD and PD packages disadvantageously adds to the manufacturing cost of the optical system.

The type E is similar to the aforementioned type D except that the spot diameter at the LD is sufficiently increased with consideration given to an oscillation in the direction of off-axis deviation, estimated from the size of a lens provided at the PD, and the PD detects a part of the light having the large spot diameter. Even if an optical-axial oscillation and oscillation in the direction of off-axis deviation take place, the amplitude of received signal will little vary in theory. Therefore, concerning the stability of received signal and performance, the type E is most suitably usable in the optical proximity spatial transmitter according to the present invention. However, since

only a part of the light having the large spot diameter is incident upon the PD, the transmission efficiency cannot be said to be high and the manufacturing cost of the optical system is slightly greater.

In the type F, the spot diameter at the PD is sufficiently increased with consideration given to an oscillation in the direction of off-axis deviation, estimated from the size of a lens provided at the LD package. Even if an optical-axial oscillation and oscillation in the direction of off-axis deviation take place, the amplitude of received signal will little vary in theory. And, the transmission efficiency is high. Therefore, concerning the stability of received signal, performance and transmission efficiency, the type F is most suitably usable in the optical proximity spatial transmitter according to the present invention. However, the manufacturing cost of the optical system is slightly greater.

When a more suitable one is selected from the above types B to F, their accuracy of rotation of the rotating system and manufacturing cost should be taken in consideration.

Experimental data on the optical performance of the type C of optical system will be explained below with reference to FIGS. 15A and 15B. It should noted however that the type C is just a suitable example of optical system for the optical proximity spatial transmitter according to the present invention and the present invention is not limited by the optical system in consideration and the experimental data. FIG. 15A shows a plotting of received signal amplitude measured at the middle of an optical path

between PD and LD provided opposite to each other with the spatial transmission distance (X-directional) from a reference position being changed, and FIG. 15B shows a plotting of received signal amplitude level measured at a constant X-directional position and with the PD position being moved little by little in two directions of off-axis deviations (Y- and Z-direction).

As shown in FIG. 15A showing measurements of optical-axial spatial transmission distance between LD and PD and of received signal amplitude, the signal amplitude level is generally constant at a position of about 0.9 mm off the reference point (0 mm on the X axis). Therefore, in an actual optical system, when a component, parallel to the optical axis, of oscillations caused by the rotation of the rotating body is about 0.9 mm (peak-to-peak), setting of the distance between LD and PD to about 0.45 mm on the X axis in the graph will permit a quality optical spatial transmission with a minimum amplitude variation of received signal.

Also, as shown in FIG. 15B showing measurements of LD and PD positions in the direction of off-axis deviations (in the Y and Z directions) and received signal amplitude, a range in which the signal level varies little is about 160 μm in the Y direction and about 140 μm in the Z direction. This range was determined by moving the optimum point of 0.45 mm in the X direction, set as in FIG. 15A. Therefore, in the actual optical system, when a component, parallel to the optical path, of oscillation caused by the rotation of the rotating body is about 0.9 mm (p-p) and components in the directions of off-axis deviations are about 150 μm (p-p) or less, a quality optical

spatial transmission with a minimum amplitude variation of received signal is possible.

Next, as embodiments of the optical proximity spatial transmitter of the aforementioned third basic construction and fourth basic construction, respectively, rotating optical couplers with a power transmission by electromagnetic coupling and with a power transmission by combination of slip ring and brush, respectively, will be described with reference to FIGS. 16 to 20. In the explanation of these embodiments, it is assumed that a data signal is sent from a rotating side which is the first communication device 52 as in the optical proximity spatial transmitter 50 of the third basic construction to the stationary side which is the second communication device 54. Contrarily, in case the data signal is sent from the second communication device 54 as the stationary side to the first communication device 52 as the rotating side, ones, concerning the signal transmission but not the power transmission, of the functions of the circuit boards at the stationary side are swapped with those at the rotating side, and each of the light emitter and photodetector provided at the rotating and stationary sides, respectively, located to take the other's place, as in the fourth basic construction.

First, each component of the rotating optical coupler 60 will be explained. The rotating optical coupler 60 does not include a motor 71, a gear 72 on the motor 71 and a mount 73 for a rotating body shown in FIG. 16. That is, the rotating optical coupler 60 consists of a rotating block 61 and stationary block 62.

As shown, the stationary block 62 has a base 621 on which a chassis 600 is fixed and also a stationary body 622 is fixed. The stationary body 622 has a circuit

board 624 fixed thereon with a circuit board fixture (stationary side) 623 placed between them. A photodetector 625 is disposed in the middle of the circuit board 624. Above, and opposite to, the incident surface of the photodetector 625, there is disposed a light emitter 611 of the rotating block 61, which will be described in detail later, with some gap formed between the incident surface and light emitter 611.

The light emitter 611 is located in the middle of a circuit board 614 mounted on a rotating body 612 with a circuit board fixture 613 placed between the circuit board 614 and rotating body 612.

In the middle of the rotating body 612, there is fixed a hollow shaft 615 having provided therein bearings 616 fixed to the chassis 600. The hollow shaft 615 has defined therein a space 617 through which an electrical lead 618 is passed. The electrical lead is led out of the circuit board 614 in the rotating block to carry a signal to be sent, and a power transmitted from the stationary side, rectified and smoothed to be a constant voltage. Also, an electrical lead 626 is led out of the circuit board 624 in the stationary block and passed through holes formed in the stationary body and base to carry a received signal.

Further, each of the stationary and rotating blocks 62 and 61 has a groove formed therein along the outer circumference thereof. In the stationary block 62, a magnetic-coupling transmitter (core) 627a is disposed along the groove. Also, in the rotating block 61, a magnetic-coupling transmitter (core) 619a is disposed along the groove. The core 627a has a plane coil 627b disposed therein, and the core 619a has

a plane coil 619b disposed therein.

As shown, the rotating optical coupler 60 is constructed with the motor 71 installed in place to give an external rotation to the rotating block 61 and the gear 72 also installed in place to transmit the rotation so that the rotating block 61 can be rotated freely with the driving force from the motor 71, a necessary power can be supplied from the stationary block 62 and a signal generated at the rotating block 61 can be supplied to the stationary block 62 with a high quality of transmission.

By forming the base 621, chassis 600 and stationary body 622 of the stationary block 62 and the rotating body 612 from a metal which will have an influence on the magnetic field, such as iron, it is possible to shield an ambient magnetic field developed at the time of a magnetic-coupling transmission and prevent the magnetic flux from leaking out of the rotating optical coupler 60, whereby permitting to reduce the influence on the surrounding circuits.

The rotating optical coupler 60 has a circuit construction and functions as will be described below with reference to FIG. 17.

Note that the description will be made on the assumption that a data signal is sent from the rotating block 61 which is a first communication device to the stationary block which is a second communication device. Contrarily, that is, for sending the data signal from the second communication device as the stationary block 62 to the first communication device as the rotating block 61, ones, concerning the signal transmission but not the power transmission, of the functions of the circuit boards at

the stationary block 62 are swapped with those at the rotating block 61, the corresponding parts of the stationary and rotating blocks 62 and 61 are swapped with each other, and each of the light emitter (LD) 611 and photodetector (PD) 625 at the rotating and stationary blocks 61 and 62, respectively, is located to take the other's place.

The rotating block 61 of the rotating optical coupler 60 is supplied with a plurality of (four in total in the drawing) parallel-transmission data DATA1, DATA2, DATA3 and reference clock (as shown) from a parallel data transmission side corresponding to the sending-side device. The rotating block 61 includes an optical-transmission encoding circuit 81. This optical-transmission encoding circuit 81 receives the above four data DATA1, DATA2, DATA3 and reference clock, and encodes the received data, to prevent signal degradation in subsequent optical transmission, by adding a redundant bit for production of a bit pattern suitable for the optical transmission and converting the pattern for easier clock reproduction at the receiving side (stationary block 62), to thereby provide parallel-transmission InData1, InData2, InData3 and InData4. The parallel transmission data after thus encoded are converted from parallel to serial by a parallel-serial converter 82 to provide a single serial signal.

The parallel-serial converter 82 outputs the serial signal at a clock frequency which is bits higher than that of the encoded parallel-transmission data in the rotating side. More specifically, when supplied with five parallel signals synchronous with each

other at a clock signal of 100 MHz for example, the parallel-serial converter 82 will output a serial signal synchronous at a clock signal of 500 MHz or more. The serial signal is supplied to an LD driver 83 which in turn will produce a sufficient modulation current to drive an LD and turn on and off an LD (at the sending side) 611 to emit light. The light is transmitted through the slight gap to a photodetector (photo diode) 625 at the stationary block 62.

The optical signal is converted by the PD 625 in the stationary block 62 into a current signal. The current signal is supplied to a PD-AMP (trans-impedance amplifier) 91 which will amplify the signal to provide a voltage modulation signal necessary only for operating a downstream logic circuit. Also, the amplifier is set to show a certain frequency response for elimination of signals in an unnecessary band and noise components, a detector 98 is provided to set a threshold level and judge logic judgment, a signal output from the detector 98 is supplied to a serial-parallel conversion circuit 92 which will reconstruct a parallel-signal clock (In clock) from the serial signal, and at the same time, the serial signal is converted into the parallel signals InDATA1, InDATA2, InDATA3 and InDATA4. These parallel signals are supplied to an optical-transmission decoding circuit 93 which will convert the parallel signals InDATA1, InDATA2, InDATA3 and InDATA4 into the parallel signals DATA1, DATA2 and DATA3 each of an initial number of bits. With the above operations, a signal to be transmitted is sent from the rotating block 61 to the stationary block 62.

In this case, the light emitter 611 in the rotating block 61 is a laser diode which

emits a communication laser of 850 nm in wavelength, and the photodetector 625 in the stationary block 62 is a GaAs photodiode. A baseband communication of about 1 Gbps (nonreturn to zero = NRZ) is made between the LD and PD by Optical spatial transfer through a gap of about 3 mm. Eye patterns of the receiving-side serial data, which are during the Optical spatial transfer, are shown in FIG. 18. Each of LD and PD is provided with the aforementioned optical system which suppresses light scattering and permits efficient incidence of light upon the incident surface of the PD.

Next, power supply by the electromagnetic coupling from the stationary body 622 to the rotating body 612 will be described with reference to FIG. 17. First, an AC power generator 94 produces an AC signal and a power driver 95 supplies an optimum amount of current to a rotating electromagnetic coupler 100. The optimum amount of current, generation frequency and shape of waveform are optimally adjusted and selected according to the inductance of coils at a stationary side 101 and rotating side 102 of the rotating electromagnetic coupler 100, coupling factor depending upon the material characteristic and shape of the core disposed near the coil, and to a coupling factor corresponding to the distance between the stationary and rotating sides, appropriate for the rotation accuracy of the rotating side for the spatial coupling, and power consumption of the devices (loads) provided at the rotating side.

The AC signal sent by the electromagnetic coupling in the rotating electromagnetic coupler 100 is rectified by a rectification and smoothing circuit 84 into a DC power. The DC power is adjusted by a voltage regulation circuit 85 to a

source voltage necessary for devices installed at the rotating side and various circuit elements at the rotating block 61 of the rotating optical coupler 60, such as the optical-transmission encoding circuit 81, parallel-serial converter 82, LD driver 83, etc., and it is supplied from a power supply unit 86 to various elements at the rotating side. Thus, power supply is made from the stationary block 62 to the rotating block 61.

The rotating block 61 is freely rotated according to a rotation driving force from the motor 71 driven under the control of a motor controller 75 which is controlled by a rotation control panel 74 used by an operator.

In addition to the power transmission by the electromagnetic coupling from the stationary block 62 to the rotating block 61, the power can be transmitted by the slip ring/brush structure which will be explained with reference to FIG. 19. The slip ring/brush combination has previously been described with reference to FIG. 3. That is, when the brush 11 is forced under a predetermined pressure to the slip ring 21 rotating around the axis thereof, a voltage signal sent from the stationary block 62 to the rotating block 61 along the electrical lead 626 is passed through a noise filter, and then adjusted by the voltage regulation circuit 85 to a source voltage necessary for devices provided at the rotating side and various circuit elements provided at the rotating block 61 of the rotating optical coupler, such as optical-transmission encoding circuit 81, parallel-serial converter 82, LD driver 83, etc. The power thus obtained is supplied from a power supply unit 86 to various elements at the rotating side. Thus, power supply is made from the stationary block 62 to the rotating block 61.

The other components are similar to those shown in FIG. 16 and indicated with the same or similar references as or to those for the components shown in FIG. 17. So, they will not be described in detail any further. Also, the explanation of the operations having made with reference to FIG. 16 is applicable to the operations having been described with reference to FIG. 17. So, the operations of this system will not be explained here.

There occurs some cases that the optical system should be used beyond the range defined in the method having previously been described with reference to FIG. 15. That is, when an oscillation due to the rotation is beyond the aforementioned allowable range, the signal amplitude varies which will cause the signal transmission to be incorrect.

In such a case, an AGC circuit 96 may be additionally provided downstream of the preamplifier 91 provided downstream of the PD 625 as shown in FIG. 20 to restore the correct signal transmission or reception to some extent. In this case, however, the AGC circuit 96 has to be able to catch up with the frequency of a rotation-caused oscillation and the amplitude of a signal before supplied to the AGC circuit should not be too small but have a required S/N ratio.

Next, an application of the optical proximity spatial transmitter, adopting the aforementioned first basic construction and second basic construction, will be described.

Referring now to FIG. 21, there is shown the external views of a personal digital

assistant (PDA) with a high-speed communication function and a PDA cradle, to which the present invention is applied.

PDA has a ROM (read-only memory), for example, in which there are stored application software for functions such as ordinary PIM (personal information manager), such as electronic schedule management, electronic address book, electronic memo pad, operations list management, etc.

The PDA includes a main unit 110 having an LCD (liquid crystal display) display 111 provided at an upper portion thereof. The PDA main unit 110 has provided at a lower portion thereof a control panel 112 with a schedule button, address book button, To Do button, memo pad button, etc. The PDA main unit 110 has provided therein a CPU (central processing unit) to which an accessory memory is connected by a bus, and a display circuit, character recognition circuit, speech recognition circuit, communication circuit, etc. connected to the CPU via the bus. Further, PDA includes a speaker, camera and a microphone. Also, it is provided with a headphone terminal, and line in and out terminals. Thus, PDA is capable of sound input and output, and image acquisition by imaging. Further, PDA is provided with an IEEE (Institute of Electrical and Electronic Engineers) 1394 terminal and USB (universal serial bus). Of course, it has a modem provided therein so that it can be connected to the Internet.

The PDA main unit 110 has provided on a surface 113a of a bottom 113 thereof PDA charging terminals 114 (negative) and 115 (positive) for charging PDA, and a photodetector 116 and light emitter 117 of the optical proximity communication

device.

The PDA main unit 110 is paired with a cradle 120. The PDA cradle 120 incorporates, or has provided as accessory, charging terminals 121 (negative) and 122 (positive), light emitter 123 and photodetector 124 of the optical proximity communication device, power cord 126, data signal cord 125.

When the PDA main unit 110 is seated in the PDA cradle 120, the cradle charging terminal 121 (negative) and PDA charging terminal 114 (negative) are put in close contact with each other while the cradle charging terminal 122 (positive) and PDA charging terminal 115 (positive) are put in close contact with each other for charging the PDA main unit 110. At the same time, light emitter 123 and photodetector 116 of the optical proximity communication device face each other while the photodetector 124 and light emitter 117 also face each other, both with a gap defined between them. That is, when the PDA main unit 110 is seated in the PDA cradle 120, the two sets of the optical proximity communication device according to the present invention are ready for communication between them. In this condition, the PDA 110 can be charged and bidirectional communications can be done between the PDA main unit 110 and PDA cradle 120 by the two sets of the optical proximity communication devices according to the present invention.

The system composed of the PAD main unit 110 and cradle 120 is advantageous as follows by using the optical proximity spatial transmitters of the first basic construction and second basic construction, respectively. That is, the PDA main

unit 110 can be seated in the PDA cradle 120 with no mechanical displacement between them, and thus communication fault hardly takes place. Also, since communications are made between two sets of LD and PD, no electromagnetic wave is used so that the peripheral devices can be little influenced by any electromagnetic wave and data can hardly be intercepted. Also, each of the two sets of the optical proximity communication devices can make bidirectional communications at a transfer rate of 200 Mbps or more.

Next, an application of the rotating optical coupler adopting the optical proximity spatial transmitter of the aforementioned third basic construction and fourth basic construction, will be described.

FIG. 22 shows the construction of a rotating monitor VTR camera system 130 to which the present invention is applied. The rotating monitor VTR camera system 130 is an example using a rotating optical coupler of such a type that data signal is transmitted by the optical proximity spatial transmission and power is supplied by the electromagnetic coupling.

As shown in FIG. 22, the rotating monitor VTR camera system 130 includes a video camera body 131, video camera lens 132, rotating block 61 and stationary block 62 of the rotating optical coupler, motor 71 for supplying a rotation driving force, mount base 140, rotation control box 141, and a display unit 142 which displays an image picked up by the camera.

FIG. 23 shows the connection among the video camera body 131, rotating block

61 and stationary block 62 of the rotating optical coupler, and motor 71. The rotating optical coupler section of this system, namely, the rotating block 61 and stationary block 62 of the rotating optical coupler, is constructed, and their peripheral parts are disposed, as in the rotating optical coupler 60 shown in FIGS. 16 and 17.

As will be seen from FIG. 23, an image light from an object is incident upon the video camera lens 132 of the video camera body 131 mounted on the rotating block 61 of the rotating optical coupler. This image light is incident upon the incident surface of a CCD (charge-coupled device) 133 and converted by the CCD 133 to an electrical signal. The signal is supplied to a video signal processor 134 where it will be adjusted in color, has noise filtered out or otherwise processed. The signal output from the video signal processor 134 goes to an output interface 135 where it will be combined with each color information of the image, sync signal and frame signal to provide digital VTR output signals. These signals are supplied together with a reference clock signal to a data signal input of the rotating block 61 of the rotating optical coupler. More specifically, four parallel data signals, namely DATA1, DATA2 and DATA3 and reference clock in FIG. 23, are supplied to the rotating block 61. Subsequently, the data and reference clock will be transmitted inside the rotating optical coupler 60 as having previously been described with reference to FIG. 17.

The digital VTR signals transmitted to the stationary side are supplied to a TV monitor via a "VTR signal converter" which converts a digital VTR signal into an analog signal which can be supplied to an ordinary TV monitor.

The video camera body 131 mounted on the rotating block 61 is supplied with an external power. The power is supplied to the stationary block 62 of the rotating optical coupler 60, and an AC signal produced by a AC power generator 94 at the stationary block 62 of the rotating optical coupler is sent to the rotating block 61 by the electromagnetic coupling in the rotating electromagnetic coupler 100. The AC signal is rectified and smoothed by the rectification/smoothing circuit 84 at the rotating block 61, regulated by the voltage regulation circuit 85 to a constant-level DC voltage, and supplied to the video camera body 131 via the power supply unit 86.

The rotation of the rotating block 61 having the camera mounted thereon is controlled by the operator using rotation start and stop switches, rotating direction control switch and a rotation speed control switch provided on the rotation control panel 74. A switch operation is converted by the rotation control panel 74 into an appropriate electrical signal. The electrical signal is supplied to the motor controller 75 in which it will be converted into a signal suitable for controlling the motor. Thus, the motor 71 is controlled with that signal.

An image captured by the rotating camera is thus displayed on the display unit 142.

FIG. 24 shows the construction of an application of the present invention in which the aforementioned slip ring/brush combination is used for supplying a power from the stationary block to the rotating block. As the brush 11 is forced under a predetermined pressure to the slip ring 21 being rotated around an axis, a voltage

signal is sent from the stationary block 62 to the rotating block 61 via an electrical lead. The voltage signal is passed through the noise filter 87 to the voltage regulation circuit 85 which will regulate the voltage signal to a constant-level DC voltage. The DC voltage is supplied to the video camera body 131 via the power supply unit 86. Since the rotating optical coupler operates as mentioned above, the operation will not be described here.

As having been described in the foregoing, the present invention provides a optical proximity spatial transmitter allowing communications between two communication devices not in contact with each other but spaced a short distance of several μm to several cm from each other, or between one and many such devices. Even during a communication, one of the mating devices can be moved, rotated or oscillated within a range limited by an intended use. Communications can be done at a transfer rate of 200 Mbps or more with a minimum influence on and by any peripheral electronic circuit or electronic device and an extremely low possibility of interception of data being transmitted between the communication devices. In addition, the optical proximity spatial transmitter according to the present invention can be produced with a lower cost.

Also, for various kinds of intended use such as transmission of data from a stationary side to a counterpart being rotated around the axis thereof or vice versa, a power can be supplied between both such sides by either the conductor contact system (slip ring/brush) or electromagnetic coupling while data signal can be transmitted

between both the sides by the optical coupling. That is, adopting a combination of the conductor contact system or electromagnetic coupling with the optical coupling, the present invention can assure quality data communications at a high transfer rate of 200 Mbps or more without any influence by crosstalk or the like.

Further, since data transfer between the communication devices is made in the noncontact manner, any change in the positional relation between the devices due to a movement, rotation or oscillation of either of the devices within the range limited by an intended use will not cause any contact abrasion or fatigue differently from the conventional contact transmission system.

Next, another application of the optical proximity spatial transmitter according to the present invention, adopting the aforementioned third and fourth basic constructions, will be described with reference to FIGS. 25 to 28. The application is a rotating drum head unit indicated with a reference 150.

In the conventional helical scan tape magnetic recording, a rotary transformer (will be referred to as "RT" hereinafter) using the electromagnetic coupling is used for transmission of a recording signal to a rotating drum or of a read signal from the rotating head.

In the helical scan tape magnetic recording, the transfer rate is demanded to be higher and higher. Generally, for an increased transfer rate, it is one of the possible approaches to increase the number of revolutions of the rotating drum. An increased number of revolutions will lead to an increased speed of the drum in relation to the

magnetic tape. In the RT system, however, the transfer frequency is limited (to a maximum of about 100 MHz) and thus the increase of the relative speed is limited correspondingly. Another one of the possible approaches is to increase the number of heads mounted on the rotating drum. In this case, however, the number of RT channels will increase and thus the RT itself will physically larger. This leads to a larger drum, which is not desirable for the current and future products of the helical scan tape magnetic recorder. Also, the space between the RT channels have to be narrow for accommodating the physical size of the RT itself. In this case, however, since the RT is of an electromagnetic coupling type, inter-channel crosstalk will be increased. Also, crosstalk between the heads and RT heads will be larger.

To overcome the above-mentioned drawbacks, the rotating drum head unit 150 is embodied as an optical-transmission drum having an optical-transmission RT as shown in FIG. 25. This drum will be referred to as "optical-transmission rotating drum head unit" 150 hereinafter. As shown, the unit 150 includes a rotating drum 151, stationary drum 171, chassis-mounted write/read control board 181, and optical fibers 190.

The rotating drum 151 has a rotating head-mounted write/read control board 152 installed thereon. On the rotating drum 151, a photodetector 153 with a recording signal receiving lens, and a light emitter 154 with a read signal sending lens, are provided with the optical axis thereof coincident with the rotating axis of the rotating drum 151. Also, the rotating drum 151 has a magnetic head 155 installed thereon. In

addition, a rotating block of the power-transmission rotary transformer is provided on the rotating drum 151.

The stationary drum 171 has a stationary block 172 of the power-transmission rotary transformer provided thereon. A hollow shaft bearing (optical spatial transfer space) 160 is provided in a position including the axis of rotation through the rotating and stationary drums 151 and 171.

The chassis-mounted write/read control board 181 has provided thereon a parallel-serial converter, amplifier and a power signal generator. Also, on this write/read control board 181, there are provided a light emitter with a recording signal sending lens and fiber connector 182 and a photodetector 183 with a read signal receiving lens.

The optical fibers 190 are connected to the light emitter with a recording signal sending lens and fiber connector 182 provided on the chassis-mounted write/read control board 181 to guide light emitted from the light emitter to the photodetector 153 with the recording signal receiving lens provided at the rotating drum 151 through a fiber connector 191 with a collimator lens. Also, the optical fibers 190 guide light emitted from the light emitter 154 with the read signal sending lens provided at the rotating drum 151 to the photodetector 183 with a read signal receiving lens provided on the chassis-mounted write/read control board 181 through a fiber connector 192 with a collimator lens.

Also, an AC voltage generated by the power signal generator on the chassis-

mounted write/read control board 181 is supplied to the stationary drum 171 through a power signal cable 195.

The optical-transmission rotating drum head unit 150 constructed as above functions in recording, playback and power supply will be described below.

First, the recording or write operation will be explained. A recording signal from each channel is converted by the parallel-serial converter on the write/read control board 181 mounted on the chassis into a serial signal, and a modulated light emitted from the light emitter inside the light emitter with a recording signal sending lens and fiber connector 182 goes into the optical fiber 190. A collimator lens provided at the other end of the optical fiber 190 collimates the modulated light having traveled through the optical fiber 190, and the light thus collimated is incident upon the photodetector 153 with a lens, disposed on the rotating drum-mounted write/read control board 152. Then, the modulated light is photoelectrically converted and amplified to a suitable voltage level in the drum-mounted write/read control board 152, has the waveform thereof shaped by the filter, then has a threshold level thereof determined by the detector, undergoes a logic determination and then converted to a parallel signal before being sent to each channel. The record amplifier supplies a recording current to the magnetic head 155 for each channel. The magnetic head 155 produces a magnetic flux which will be recorded as a magnetic pattern on the magnetic tape.

Next, the playback or reading operation will be described. The magnetic head

155 reads a magnetic pattern recorded on the magnetic tape and converts it into a current signal. The signal is amplified by a read head amplifier in the rotating drum-mounted write/read control board 152 to an appropriate voltage level. A change in signal characteristic, caused incidentally to the magnetic recording characteristic, is equalized by a equalizing circuit and encoded by the encoding circuit for error correction or the like. Thereafter, for the optical transmission, the signal from each channel is converted by the parallel-serial converter into a serial signal, the serial signal is converted by the light emitter driver into a current signal which can drive the light emitter, and an optical signal is emitted from the light emitter 154 with a lens toward the hollow shaft bearing 160. The light travels in the bearing 160, and then it is incident from the fiber connector 192 with a collimator lens upon the optical fiber 190, transmitted through the optical fiber 190, incident upon the photodetector 183 with a read signal receiving lens and photoelectrically converted. Further, the signal is amplified by the amplifier on the chassis-mounted write/read control board 181 to be provided as a voltage signal. The voltage signal has the level thereof optimized and the waveform thereof shaped by the filter. Then, it has the threshold level thereof determined by the detector and undergoes a logic determination. Then, the signal is converted by a serial-parallel converter into a parallel signal to provide a signal for each channel.

In the optical-transmission rotating drum head unit 150, a power is supplied as will be described below. The chassis-mounted write/read control board 181 produces

an AC voltage by a power signal generator therein. The AC voltage is supplied to the stationary drum 171 along a power signal lead 195. Inside the drum, the power signal is supplied from the stationary drum 171 to the stationary block 172 in the rotary transformer. The supplied signal is electromagnetically coupled to the rotating block of the rotary transformer and sent to the rotating head-mounted write/read control board 152. The power signal thus transmitted is passed through the rectification circuit and voltage regulation circuit provided on the board 152 to provide a constant DC voltage which will be supplied to each electronic circuit elements on the board 152.

The chassis-mounted write/read control board 181 supplies a power to the stationary drum 171 via the power signal lead 195 and a recording light to the write/read control board 152 provided on the rotating drum 151, and is supplied with a read light from the write/read control board 152. The write/read control boards 181 and 152 are constructed and function as will be described below in detail.

First, the chassis-mounted write/read control board 181 will be explained with reference to FIG. 26. This circuit board is generally composed of three blocks: a power supply unit 200, write control unit 210 and a read control unit 220.

The power supply unit 200 is provided to supply a power to the rotating block 151 of the rotating drum through the rotary transformer. There is also provided an AC generator/driver 201 for a power rotary transformer 202, which produces an AC for the power rotary transformer 202 to drive the latter. The AC generator/driver 201 for the power rotary transformer 202 produces a rectangular-, trapezoidal- or sinusoidal-

wave AC. This signal is sent to the rotary transformer 202. The oscillation frequency and amplitude voltage, current, etc. are determined depending upon the thickness and wound state of the winding of the rotary transformer 202, gap size, core material, power consumption at the rotating block, etc. for a better efficiency of each system.

The write control unit 210 is provided to modulate signals (chA Write, chB Write, chC Write and chD Write) to be written to the magnetic tape, sent from the chassis to each channel of the magnetic head, and emits the modulated signals as light from a light emitter 214 provided in the light emitter with a recording signal sending lens and fiber connector 182. At this time, the write control unit 210 is supplied with a system clock from the chassis. There is provided an optical-transmission modulator 211 which modulates the recording signals (chA Write, chB Write, chC Write and chD Write) based on the system clock for optical transmission. This modulation is optimum for attaining the intended purpose of write control. At the same time, an error collection bit is added. Then, multi-channel parallel signals are converted by a parallel-serial converter in a transceiver circuit 212 into a serial signal which will be sent to an LD driver 213. The LD driver 213 produces a drive current which is used to drive the light emitter 214. Thus, the light emitter 214 is driven to emit light and turned on and off according to a predetermined modulation pattern.

Next, the read control unit 220 will be described. The read control unit 220 is provided to receive and demodulate a read optical signal sent from the rotating drum-mounted write/read control board 152. The optical signal sent from the light emitter

154 on the rotating drum-mounted write/read control board 152 is photoelectrically converted by a photodetector 221 of the photodetector 183 with a read signal receiving lens to provide a current. This current is amplified by an amplifier 222 to an optimum voltage level, has the waveform thereof shaped by a filter 223, has the threshold level thereof determined by a detector 226, undergoes a logic determination, and is then sent to a receiver circuit 224. The serial signal is restored by the receiver circuit 224 to a parallel signal, and sent to an optical-transmission demodulator 225 in which it is demodulated (and has errors thereof corrected). The read signal from each channel, thus demodulated, is returned to parallel data (chA Read, chB Read, chC Read and chD Read) and sent to the chassis. It should be noted that the clock restored from the serial signal added by a filter 223 is returned to the optical-transmission demodulator 225 and chassis.

Next, the rotating drum-mounted write/read control board 152 will be explained. This circuit board is also generally composed of three functional parts: power supply unit, write control unit and read control unit.

The power supply unit will be described below. It is supplied with the AC signal from the stationary block 171 of the drum head as a result of the electromagnetic coupling from the power rotary transformer 202. The signal is passed through a rectification/smoothing circuit and voltage regulation circuit 231 to provide a constant-voltage power which will be supplied to each of the electronic circuit elements on the circuit board.

In the write control unit, the write optical signal sent from the chassis (stationary block) is photoelectrically converted by a photodetector 241 into an electrical signal. This electrical signal is amplified by an amplifier 242 to an optimum voltage level, has the waveform thereof shaped by a filter 243 and the threshold level thereof determined by a detector 249, undergoes a logic determination and then is sent to a receiver circuit 244. The receiver circuit 244 converts the serial data into parallel data, and supplies them to an optical-transmission demodulation circuit 245. The optical-transmission demodulation circuit 245 demodulates (and corrects errors of) the supplied signals. As a result, the signal is restored to a recording signal for each channel, and sent to a magnetic-recording encoding circuit 246 (and has an error-correction bit added thereto) in which it is encoded suitably for the magnetic-recording channel. Then, the signal is sent to each write head amplifier 247 in which it will be amplified. Each write head 248 converts the amplified electrical signal into a magnetic signal and forms a magnetic pattern on the tape.

In the read control unit, the magnetic pattern formed on the tape is converted by each read head 251 into a read electrical signal, and the signal is amplified by each read amplifier 252 to an optimum voltage level. Then, a magnetic-recording decoding circuit 253 restores (and corrects errors of) signals having been in an optimum code series for magnetic recording. Next, the signal is passed to an optical-transmission modulation circuit 254 in which (it will have an error correction bit added thereto and) it will be modulated optimally for the optical transmission. Then, the multi-channel

parallel signals are converted by a transceiver circuit 255 into a serial signal, a light emitter 257 is driven by a light emitter driver 256, and thus the light emitter 257 is turned on and off to produce an optical signal. It should be noted that the read clock restored by the magnetic-recording decoding circuit 253 is optimized, sent to the optical-transmission modulation circuit 254 and transceiver circuit 255, in which it will be used as an optical-transmission reference clock.

Next, the optical system in the rotating drum head unit 150 will be described in detail. FIGS. 27A and 27B show the constructions of the optical system for the data write and read, respectively.

For data write, light emitted from the light emitter with a recording signal sending lens and fiber connector 182 consisting of the light emitter (LD 214) and a lens, provided on the chassis-mounted write/read control board 181, travels through the optical fiber 190, and is spatially transmitted (as indicated with a rightward rising arrow) through the fiber connector 191 with a collimator lens and incident upon the photodetector 153 with a recording signal receiving lens consisting of a photodetector (PD 241) and a lens, provided on the rotating drum-mounted write/read control board 152, as shown in FIG. 27A.

For data read, light emitted from the light emitter 154 with the read signal sending lens consisting of a light emitter (LD 257) and a lens, provided on the rotating drum-mounted write/read control board 152, is spatially transmitted through the hollow shaft (optical spatial transfer space) (as indicated with a rightward rising

arrow), guided to the optical fiber 190 through the fiber connector 192 with a collimator lens, and incident upon the photodetector 183 with a read signal receiving lens consisting of a photodetector (PD 221) and a lens, provided on the chassis-mounted write/read control board 181, as shown in FIG. 27B.

Therefore, in the rotating drum head unit 150, a short-range or proximity spatial transmission is done between the chassis-mounted write/read control board 181 at the stationary side and rotating head-mounted write/read control board 152 at the rotating side.

Note that in the foregoing, the chassis-mounted write/read control board 181 has been described as a part of the stationary drum 171 as shown in FIG. 26.

FIGS. 28A to 28D show an optical system suitable for the rotating drum head unit 150 in addition to the optical system shown in FIGS. 27A and 27B.

Basically, the short-range spatial transmission can be done by a type A in which a light emitter (which may be provided with a lens) and a photodetector (which may be provided with a lens) are provided opposite to each other. The light emitter may be provided at either the rotating block or stationary block. Of course, the photodetector may be provided at either the stationary or rotating block correspondingly to the light emitter.

Also, the short-range spatial transmission can be done by a type B in which an optical fiber (POF : plastic optical fiber) is coupled at one end thereof to a light emitter and extended at the other end thereof (which may be provided with a lens) to near the

incident surface of a photodetector (which may be provided with a lens). Also in this type B, the light emitter may be provided at either the rotating block or stationary block and thus the photodetector may be provided at either the stationary or rotating block correspondingly to the light emitter.

Also, the short-range spatial transmission can be done by a type C in which an optical fiber (POF) is coupled at one end thereof to a photodetector and extended at the other end thereof (which may be provided with a lens) to near the emitting surface of a light emitter (which may be provided with a lens). Also in this type C, the light emitter may be provided at either the rotating block or stationary block and thus the photodetector may be provided at either the stationary or rotating block correspondingly to the light emitter.

Also, the short-range spatial transmission can be done by a type D in which an optical fiber (POF) is coupled at one end thereof to each of a light emitter (which may be provided with a lens) and photodetector (which may also be provided with a lens) and the optical fibers are disposed at the other ends thereof opposite to each other. Also in this type D, the light emitter may be provided at either the rotating block or stationary block and thus the photodetector may be provided at either the stationary or rotating block correspondingly to the light emitter.

Note that in the rotating drum head unit 150, the hollow shaft 160 as the rotating drum bearing, provided in the rotating drum 151 and stationary drum 171, may be used for optical spatial transfer for the data write as well as for data read.

In the aforementioned rotating drum head unit 150, since the optical proximity spatial transmitter is provided, it is possible to reduce adverse affect of transmitted signal on the head, head amplifier, etc., namely, crosstalk, external noise, etc.

Also, even if the number of mounted heads is increased, the transmitter will not be larger (as the conventional rotary transformer) but can be designed compact and can transfer data at a high transfer rate.

In the conventional RT, the transfer rate is limited to a maximum of about 100 MHz/ch but the rotating drum head unit 150 adopting the transmitter according to the present invention can transfer data at a higher rate.

Also, since the head write/read amplifier, modulator, error correction function, etc. can be installed on the rotating drum head unit 150, quality recording and read signals are available for an improved performance of data write and read.

Further, since the transmission distance may be shorter than in the ordinary optical communication applications, the light emitter consumes less power and signal can be transmitted through a simple optical system. These features are much contributed to the economy of the apparatus.

Also, owing to the use of the light emitter and photodetector with a collimator lens or lenses, respectively, a rough positioning of the optical system will do, which leads to a considerable reduction of manufacturing steps and thus to a lower manufacturing cost.

Since the optical fiber can freely be routed to guide light to near the

photodetector (light emitter), the system components can be laid more freely in manufacturing the product.

In the optical proximity spatial transmitter according to the present invention, the anti-scattering lens is provided behind the light emitter of the first communication device and/or second communication device and/or in front of the photodetector of the communication devices, and the first communication device is rotated around the axis of rotation coincident with the optical axis of light outgoing from the light emitter and/or light incident upon the photodetector while the second communication device is stationary with the light emitter and/or photodetetcor thereof disposed on the optical axis. Therefore, the transmitter can provide inexpensive, efficient and higher-rate optical transmission of information data through an optical proximity space.

In the foregoing, the present invention has been described in detail concerning certain preferred embodiments thereof as examples with reference to the accompanying drawings. However, it should be understood by those ordinarily skilled in the art that the present invention is not limited to the embodiments but can be modified in various manners, constructed alternatively or embodied in various other forms without departing from the scope and spirit thereof as set forth and defined in the appended claims.